

Low Friction Coatings and Materials for Fuel Cell Compressors & Blowers

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Program

Background

Technology Issue: Fuel cell stacks requires a compact lightweight highly efficient compressor/expander. No off-the-shelf compressor technology can meet the stringent requirements for this application. Several contractor have and are working on developing compressor/expander systems. Efficiency, reliability and durability of such system are dependent on effective lubrication of critical components such as bearings and seals. Such components cannot be oil lubricated - oil will contaminate fuel cell stacks.

Objectives: Develop and evaluate low-friction and wear-resistant coatings and/or materials for critical components of air compressor/expanders being developed for fuel cells.

Approach:

1. Working with various contactors

- Identify tribologically challenging critical compressor components
- Apply and evaluate Argonne's near-frictionless carbon coatings to the components when appropriate
- Develop and evaluate polymer composite materials with boric acid solid lubricant.
- Identify and evaluate other candidate materials for various specific compressor components

2. Develop a material selection methodology applicable to all the DOE compressor contractor's tribological conditions and requirements

Past Accomplishments:

- Worked with various contractors to address their tribological technical barriers:

Meruit: Turbo-Compressor Air Bearing

- Developed and evaluated NFC coating for the radial and thrust air bearings - Without the NFC coating bearing cannot run. Coating reduced friction, wear and prevented scuffing or seizure.
- Conducted both lab and air bearing rig testing - Meruit has incorporated use of NFC coating into their air bearing design
- **Variex - Variable Displacement Compressor**
 - Achieved 50% reduction in friction compared to their prototype using Hitco C/C composite and anodized aluminum material combination.
 - Fabricated and evaluated friction and wear performance of Nylon-12 and boron oxide composite. Significant friction and wear reduction was observed, especially under high humidity



Past Accomplishments:

Mechanology: Toroidal Intersecting Vane Machine (TIVM)

- Designed and constructed high speed test rig to evaluate friction and wear performance of materials under the very high sliding speed typical of TIVM machine vane
- Evaluated several candidate materials for TIVM vanes

Mesoscopic Devices (in progress)

- Friction wear testing of candidate polymeric materials for blowers
- Developing NFC coating for blower vane component

AD Little: Hybrid compressor/Expander Module

UTC Fuel Cells: Motor Blower/compressor Technology

Honeywell: Turbo-compressor/Expander

Mechanology TIVM: - Tribological Issues

This compressor concept offer a great potential for meeting the size, weight, and efficiency targets.

- Initial design and prototype fabrication of TIVM completed by Mechanology
- Analysis showed that friction will significantly impact the efficiency of compressor.
- ANL working with Mechanology to develop and evaluate low friction and wear resistant surfaces for critical components.

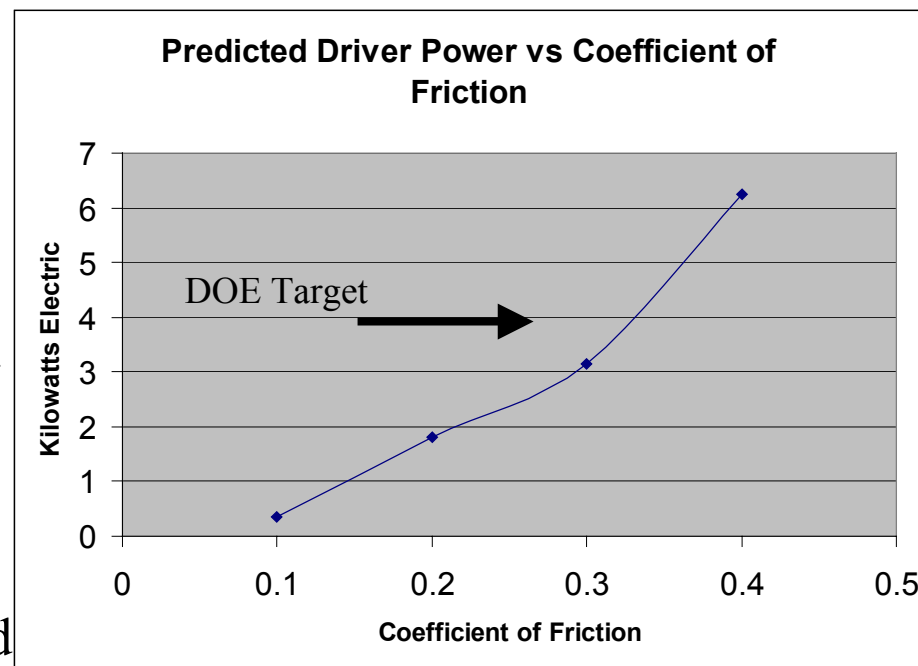


Figure from Mechanology phase I final report

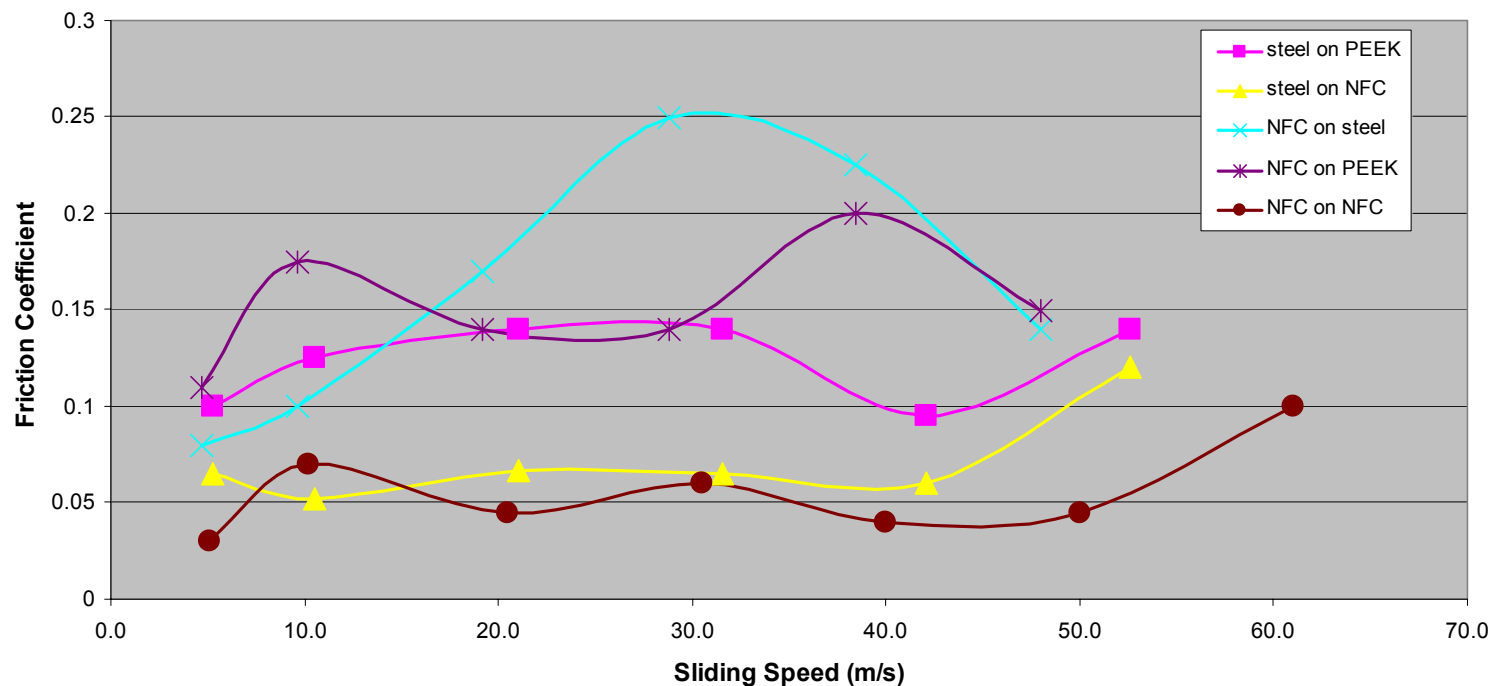
Friction Test for (TIVM) Vane Materials



- Design sliding velocity for the TIVM vanes ranges from 60 - 75 m/s
 - Need to identify materials capable of such sliding speeds.
 - Other constraints include relatively low cost, light weight, easy to fabricate,
- Friction and wear test protocol was developed to evaluate the effect of sliding speed on friction coefficient
 - Uses three balls-on-disc contact configuration
 - Run tests at selected step speed for 3 minutes at each step, then calculate average friction for each speed step.
- Several materials screened: 440 C S.S., Bronze, Teflon, Delrin, PEEK, Torlon, Vespel, Armaloy coated bronze, NFC coated steel

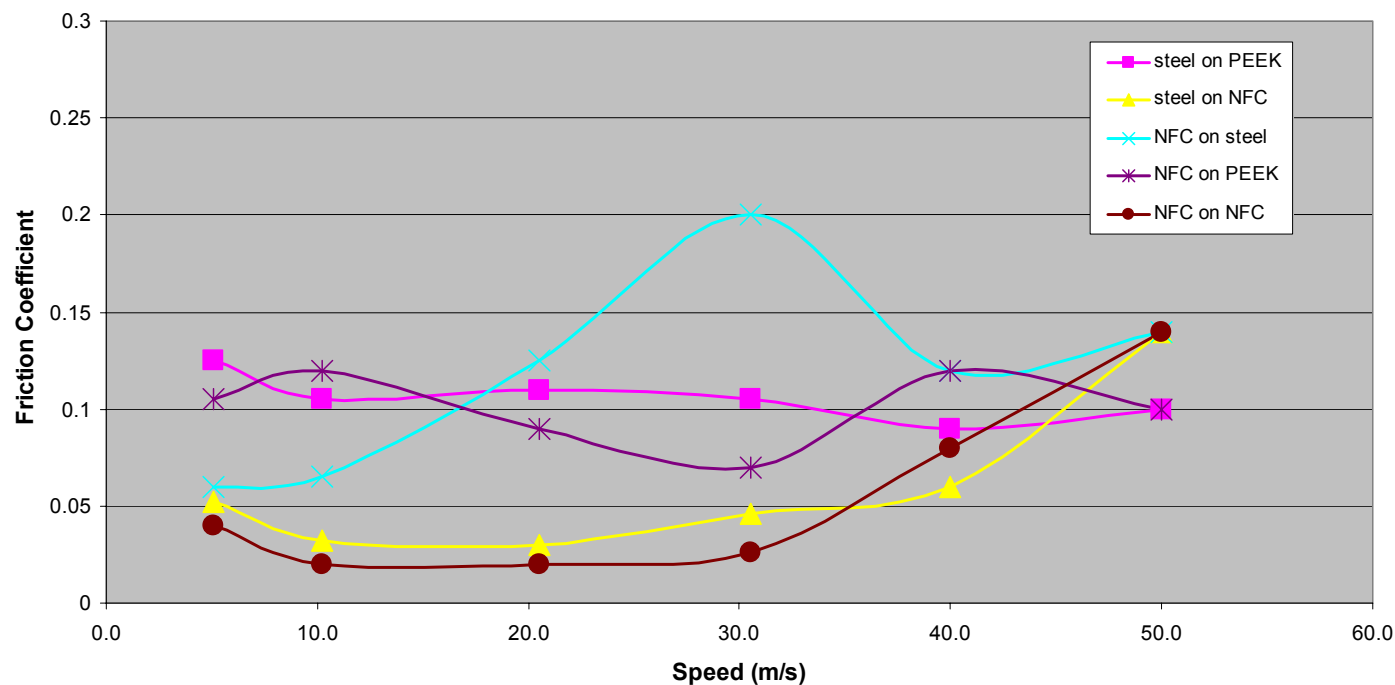
Frictional Performance – Room Air

Variation of Friction Coefficient with Sliding speed in ambient air (~30% RH) for candidate material and coating combinations



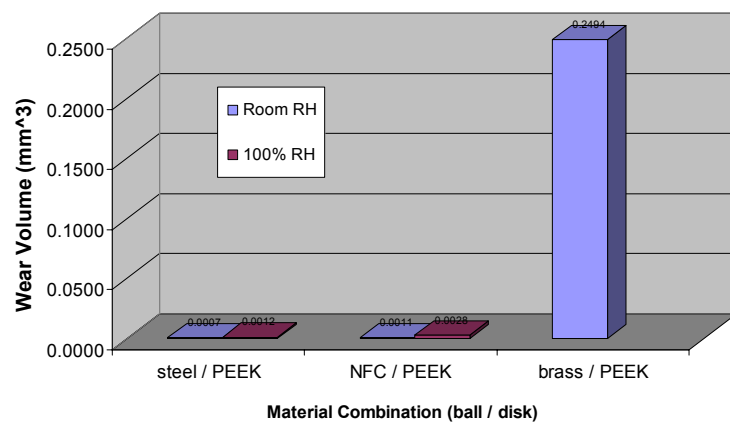
Frictional Performance – Humid Air

Variation of Friction Coefficient with Sliding Speed for Candidate materials and coatings under 100%RH

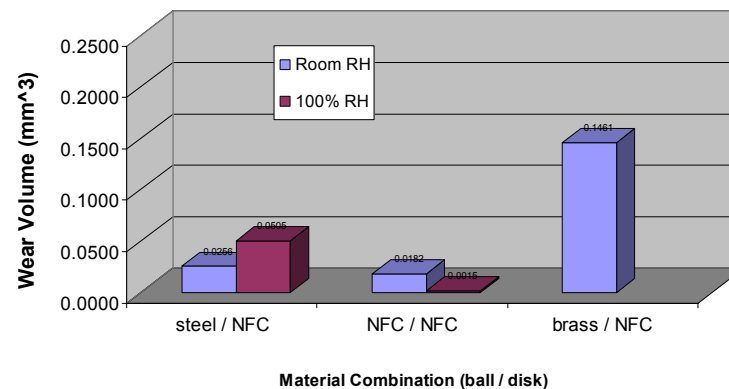


Wear Performance

Wear Volume of Balls Sliding on PEEK Disc

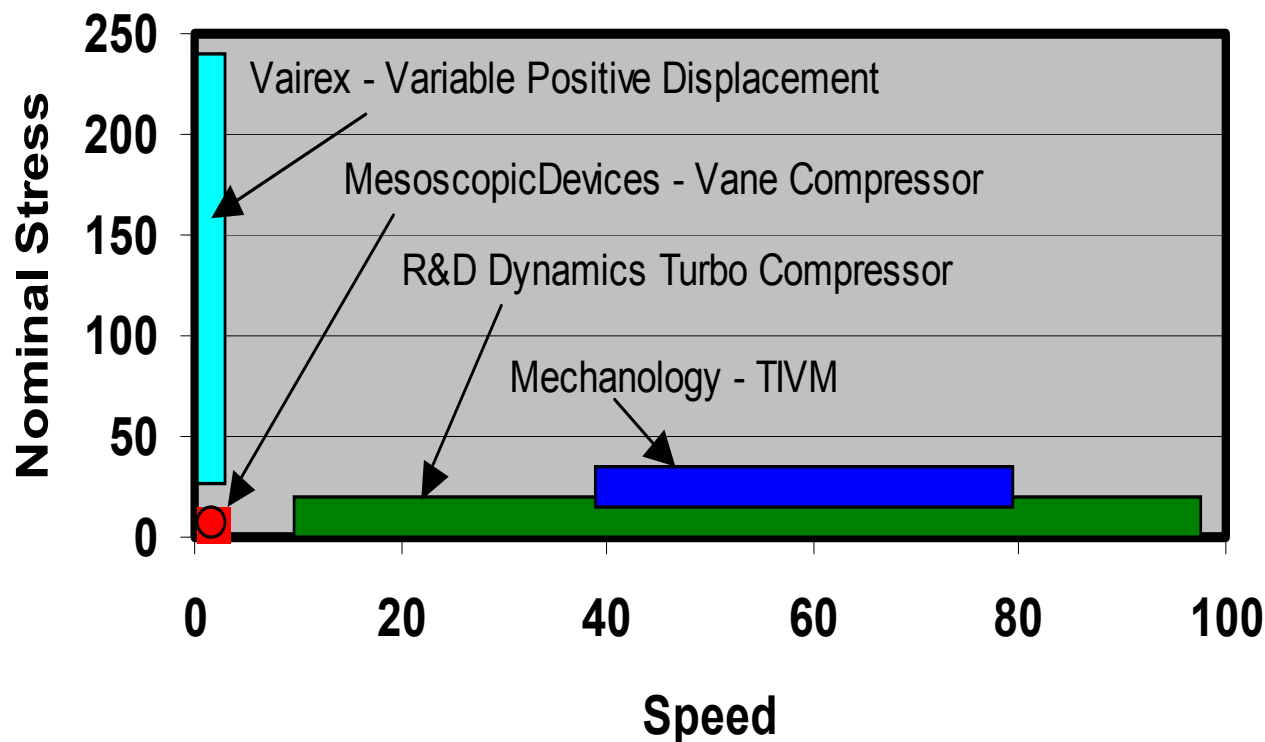


Wear Volume of Balls Sliding on NFC Disc



Different Compressor/Blower Concepts Have Widely Different Operating Parameters, and Materials

- Nominal contact stresses range for a few psi to several hundred psi
- Sliding speeds range from < 0.5 m/s to greater than 80 m/s
- Materials of construction include: polymers, metals, ceramics, carbons, and composites



Contact Temperature and Tribological Performance

At high sliding speeds typical of compressors and blowers designs, contact temperatures frictional heating governs the tribological performance.

Bulk Temperature Calculation

Rate of bulk frictional heating q_b

$$q_b = \frac{\mu F v}{A_n}$$

μ = friction Coefficient
 F = Normal Force
 v = Sliding velocity
 A_n = Nominal contact area
 A_r = Real contact area

Bulk temperature T_b

$$T_b - T_o = \frac{q}{\left[\frac{k_1}{l_{1b}} + \frac{k_2}{l_{2b}} \right]}$$

T_o = Ambient temperature
 k_1 = Thermal conductivity – body 1
 k_2 = Thermal conductivity – body 2
 l_b = nominal contact length
 l_f = asperity contact length

Flash Temperature Calculation

Rate of asperity frictional heating q_f

$$q_f = \frac{\mu F v}{A_r}$$

Flash or asperity temperature T_f

$$T_f - T_o = \frac{q_f}{\left[\frac{k_1}{l_{1f}} + \frac{k_2}{l_{2f}} \right]}$$

Concept of T-Maps – Methodology to Calculate Bulk and Asperity Heating Based on Frictional Heating

Main Heading:
Configuration,
Materials,
Contact Radius,
Asperity Radius,
Ambient Temperature

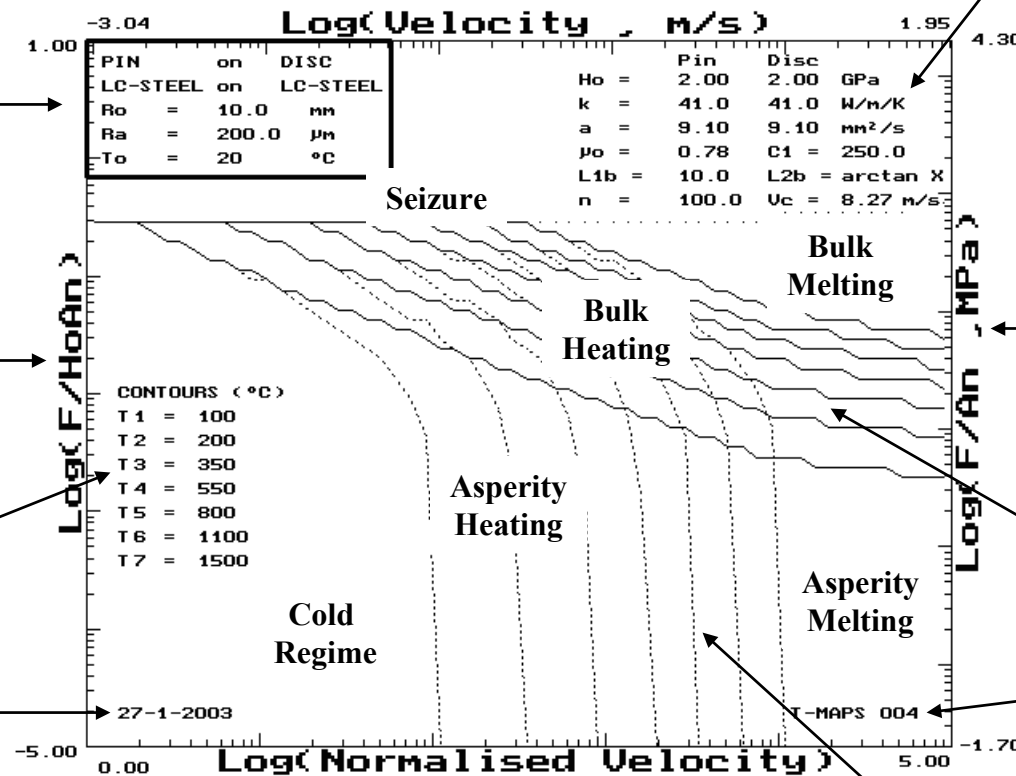
Axis of Sliding
Velocity (m/s)

Material Data:
Hardness,
T-Conductivity,
T-Diffusivity,
Friction Constants,
Heat-Diffusion Lengths,
Asperity Lifetime and
Asperity-Melting Velocity

Axis of
Normalized
Bearing Pressure

Temperature
Contour C

Date of
Computation



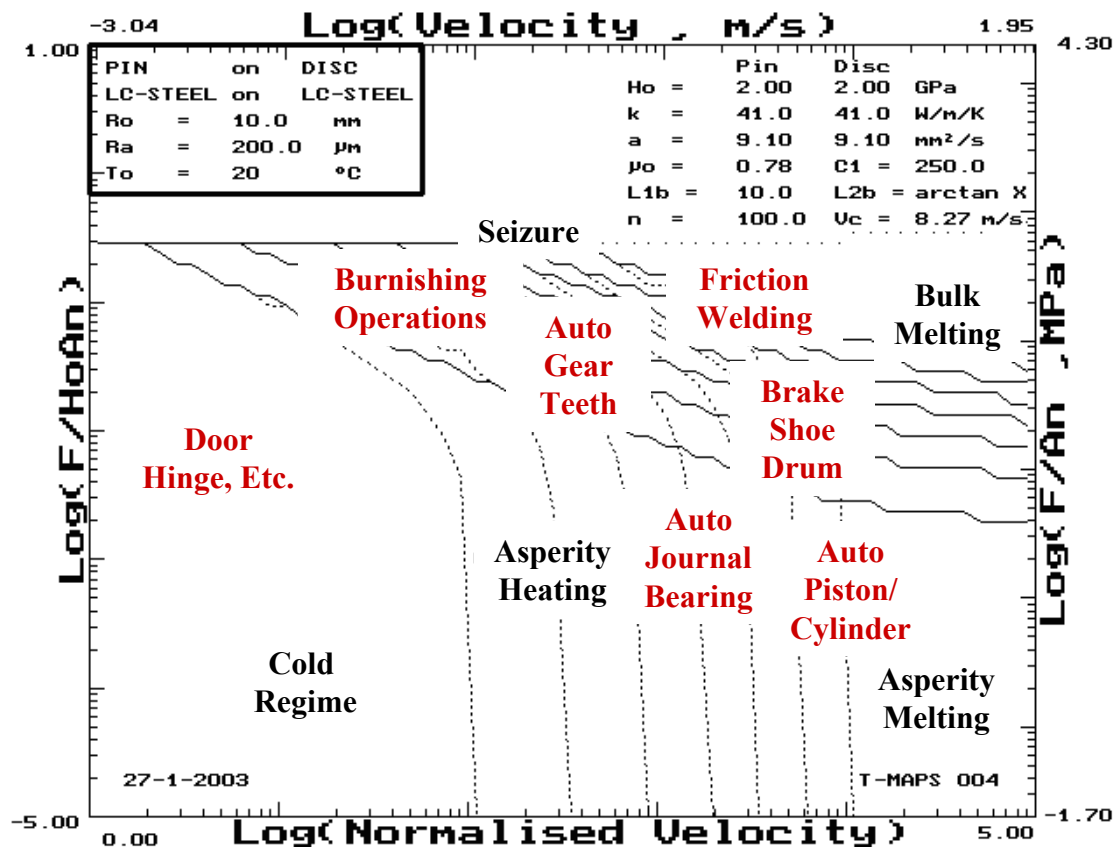
Axis of
Normalized
Sliding Velocity

Contours of Asperity
Temperature

Concept of T-Maps – Methodology to Calculate Bulk and Asperity Heating Based on Frictional Heating

Based on operating contact conditions and material properties, map the various possible modes of failure.

- T-Map as an illustration of effect of sliding conditions on friction heating and failure mechanisms.





Future Activities

- Continue Collaborations with DOE supported Compressor/Blower Partners to Address Tribological & Material Issues
 - Mechanology
 - Meruit (respond to DOE solicitations as subcontractor where appropriate)
- Initiate Collaborations with:
 - UTC (R&D Dynamics) – Compressor
 - AD Little
 - Others
- Work with firms developing blowers for portable fuel cell applications (50 W to 5 kW)
- Host Compressor/Blower Workshop to Identify Critical Material Issues/Barriers
- Develop Material Selection Methodology Model
 - Wear/Friction Maps



Energy Technology Division - Tribology





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